CORNING GLASS WORKS

ELECTRO-OPTICS DEPARTMENT

RALEIGH, NORTH CAROLINA

IMPROVED SCREEN FOR REAR-PROJECTION VIEWERS

Technical Report No. - 39

Date — March 28, 1969

Period Covered — February 28, 1969

to

March 28, 1969

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Declassified in Part - Sanitized Copy Approved for Release 2012/09/06 : CIA-RDP79B00873A001900010038-3

1. Scattering Screens

Work is continuing on the adaptation of previously developed in-house materials and techniques to the fabrication of usable 12-1/8" x 15-1/8" sample screens for subjective testing.

1.1 The AM Series (Medium particle size, low index ratio).

A series of 18 screens were made with various values of glass-to-binder volume ratio. The typical particle size was approximately 2 microns. Since the ratio of glass refractive index to binder index was 1.04, these were predominately surface-scattering screens. Table 1 lists the screen parameters and measured characteristics. Some screens were cast on gray glass substrates; hence the substrate transmittance is tabulated also.

1.1.1 Brightness Variation

The measured brightness variation values V_{45} are plotted in Fig. 1 as a function of axial gain B(0). The smooth curve is a best fit to the AM series data. This curve thus provides an empirical standard against which individual screens can be evaluated. The measurement technique for V_{45} in principle is not affected by a darkened substrate. However, the overall screen gain as determined by our measurement techniques includes the substrate transmittance as a constant factor. Hence the measured axial gain of a darkened-substrate screen must be multiplied by the ratio of clear substrate transmittance to dark substrate transmittance in order to obtain the axial gain of the scattering layer itself. The darkened substrate data, thus adjusted, are seen to fall near the curve.

1.1.2 Efficiency, T_{45}

Figure 2 shows measured T_{45} and the best-fit curve for the AM series data. This curve falls below the theoretical curves calculated in P-19-30 for a volume scatterer in a thin film on no substrate. This is explained at least partly by the fact that in the substrateless thin layer, the trapped light contributes to the efficiency. When a thick substrate is used, however, trapped light does not contribute to the efficiency and our measurement procedures exclude it from the transmitted light.

The measured gain and measured T_{45} each contain the substrate transmittance as a constant factor. Hence each must be multiplied by the ratio of clear to darkened transmittances in order to characterize the scattering layer alone. Data for darkened substrate screens then fall in line with the others.

1.1.3 Dependence on glass-to-binder volume ratio

Most of the screens of this series fall outside the useful region of brightness variation. Figure 3 indicates why this is true. As a function of glass-binder ratio, the brightness variation drops sharply as it approaches the desirable 30-60% region. The dependence is so steep, in fact, that reproducibility and uniformity cannot be maintained. For this reason it has been decided to select a less steep portion of the curve, e.g. a glass-binder ratio of 0.57, and to obtain wider scattering by increasing layer thickness. Hopefully, this will not degrade resolution critically, since most of the scattering occurs at the glass-air interface.

1.2 The AL Series (Coarser particles, low index ratio)

Screens AL-2, 4 and 5, listed in Table I are similar to the AM series except that the glass particles were ball-milled for a shorter time, resulting in somewhat coarser particles. Screens AL-4 and AL-5 are relatively uniform, 12-1/8" x 15-1/8", screens suitable for subjective testing. However, the brightness variation of 72% is probably too high and Fig. 2 shows that their efficiency is lower than other screens of this composition.

1.3 Trapped Projector Light

A direct measurement of trapped projector light can be accomplished by exploiting the thick-substrate geometry shown in Fig. 4. Uniform projector light falls upon the scattering layer 1 and is scattered toward plane surface 2, where it is largely transmitted, or, when impinging at angles greater than the critical angle θ_c, it is totally reflected back to surface 1. There it is diffusely transmitted and reflected. A portion of this diffusely reflected light is finally transmitted at surface 2. Let the substrate thickness be t. If an opaque disk of diameter

$$D \geq 4\, t \tan \theta_c \qquad (1)$$

is placed against surface 1 and an opaque mask with a hole of diameter

$$d \leq 2\, t \tan \theta_c \qquad (2)$$

is placed concentrically against surface 2, then no directly transmitted light can arrive at the detector and a maximum amount of trapped light is observed by the detector. Some trapped light originating from all illuminated parts of surface 1 finds its way to the area behind the opaque disk and is observed by the detector as a trapped light brightness B_T. When the opaque disk is removed, the detector observes the sum of the direct brightness B_D and trapped brightness B_T. The "trapped light ratio"

$$\alpha_T = B_T/B_D \qquad (3)$$

is a sensitive measure of the tendency of a screen to transmit spurious, contrast-degrading, light to the viewer. If the contrast in an image without trapped light is

$$\gamma_0 = \frac{B_{max} - B_{min}}{B_{max} + B_{min}} \quad , \qquad (4)$$

add B_T to each quantity

then with trapped light, the contrast is degraded to

$$\gamma = \frac{\gamma_0}{1 + \dfrac{2B_T}{B_{max} + B_{min}}} \quad . \qquad (5)$$

Divide through by a factor to normalize ?

Now, suppose that the average brightness at the point in question of a displayed image is 1/N as great as the average directly transmitted brightness B_D of the entire display, i.e.,

$$\frac{B_{max} + B_{min}}{2} = \frac{B_D}{N} \quad . \qquad (6)$$

Condition (6), definition (3), and equation (5) then give

$$\frac{\gamma}{\gamma_0} = \frac{1}{1 + N\alpha_T} \quad , \qquad (7)$$

the contrast factor at the point in question. For acceptable contrast degradation, say $\gamma/\gamma_0 \geq 0.9$, equation (7) yields

$$\alpha_T \leq \frac{1}{9N} \quad . \qquad (8)$$

This restriction on α_T applies strictly to the case of an essentially uniformly bright display which is N times brighter than a small, less bright, area of interest. The condition is even more stringent if nearby brighter-than-average regions are considered. However, it is very difficult to satisfy condition (8) itself with scattering screens. In principle, trapped projector light can be completely eliminated in scattering screens by making the substrate sufficiently thin or sufficiently thick. A scattering screen of total thickness much less than a resolution element confines trapped projector light to the resolution element from which it originates and suffers no loss in contrast. On the other hand, a substrate thickness of the order of one-half the screen width allows trapped light to be transmitted out through the sides where it can be absorbed or otherwise eliminated from the system. In the case of intermediate thickness under consideration at present, condition (8) must be satisfied by absorption in the substrate.

The trapped light ratio α_T was measured for a number of screens of the AM series. The acceptance angle of the detector was arbitrarily set large enough to contain most of the visual angular field of $\pm 45^{\circ}$. Measured values α_T are plotted against axial gain in Fig. 5. The curve indicates that a screen typical of this series and having an axial gain of 2.5 would have α_T = 10%. If it is desired to view, at 90% contrast, areas of 100-fold less-than-average brightness, equation (8) implies $\alpha_T \lesssim 1/900$. The required additional factor of 90 can be obtained by use of a substrate of transmittance approximately 10%, since trapped light must make two passes more through the substrate than does direct light. This example illustrates the important trade-off between brightness range N and efficiency, for this type of screen.

2. Lenticular Screens

An order has been placed with Rowland Products, Inc. to produce cylindrical plastic lenticular sheets for our use in studying the feasibility of the crossed cylinder approach to lenticular screen fabrication. While waiting for the completion of these sheets we will be working out the necessary masking, joining and supporting techniques. Other approaches are under study.

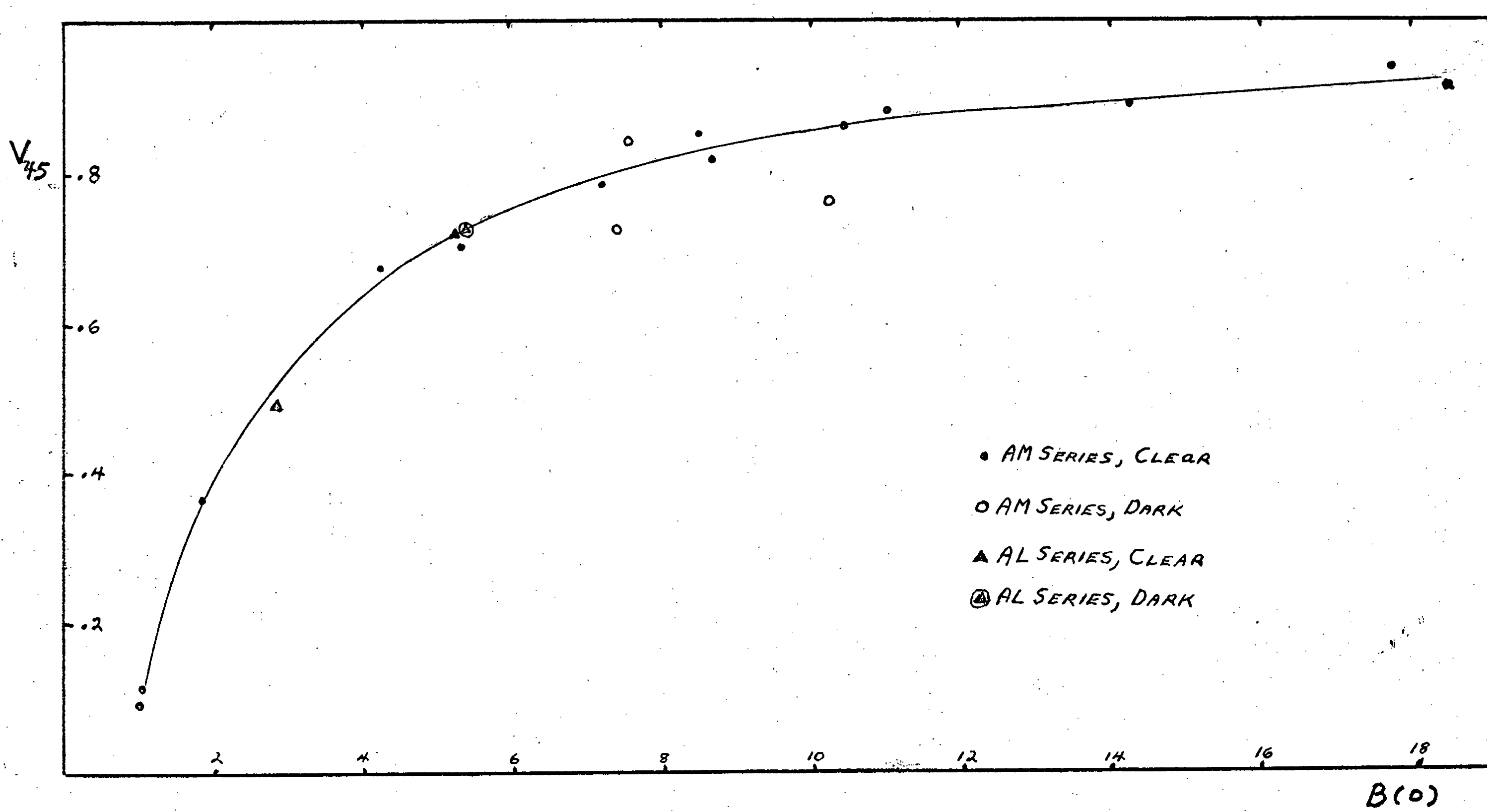

Figure 1. Brightness variation V_{45} versus axial gain B(0) for the AM and AL series.

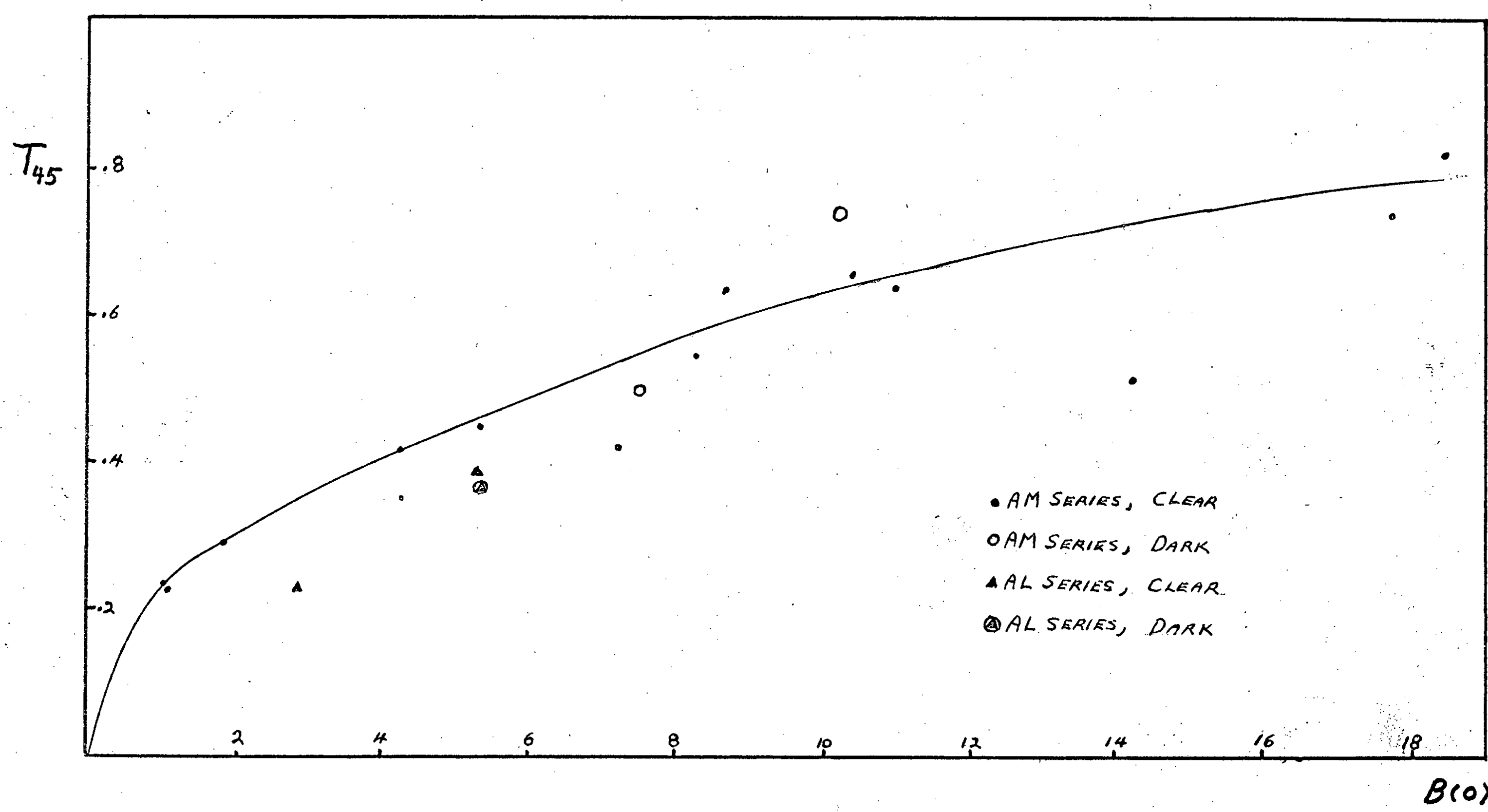

Figure 2. Efficiency T_{45} versus axial gain for the AM and AL series.

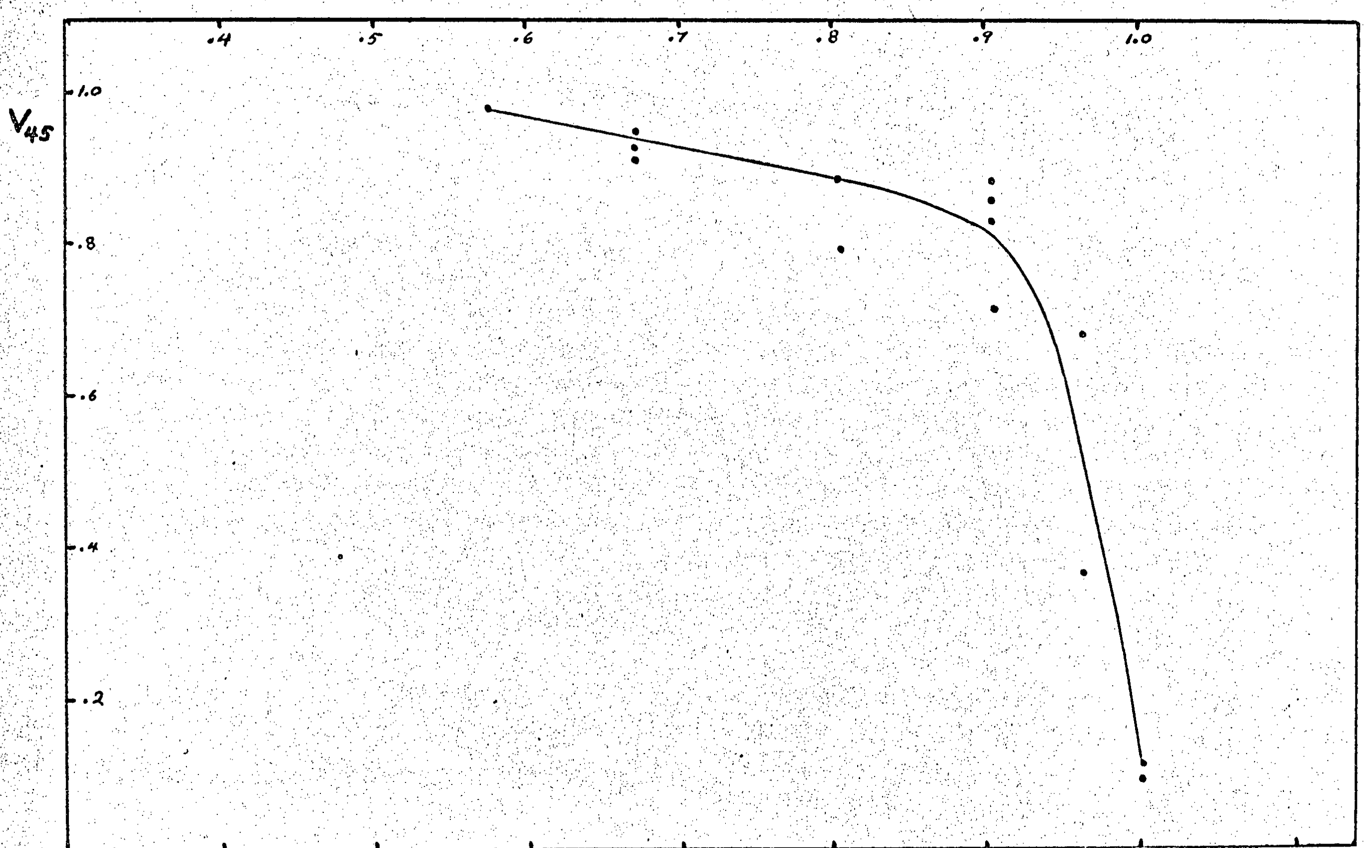

Figure 3. Brightness variation versus glass-binder volume ratio for series AM.

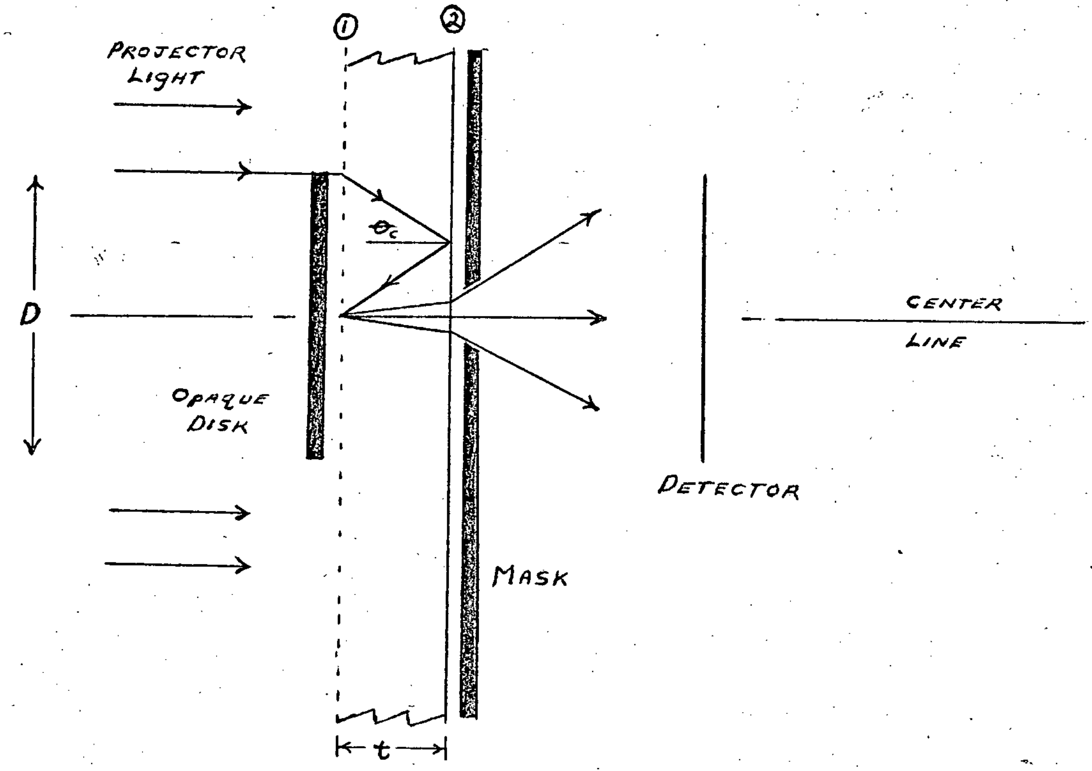

Figure 4. Geometry for measurement of trapped projector light.

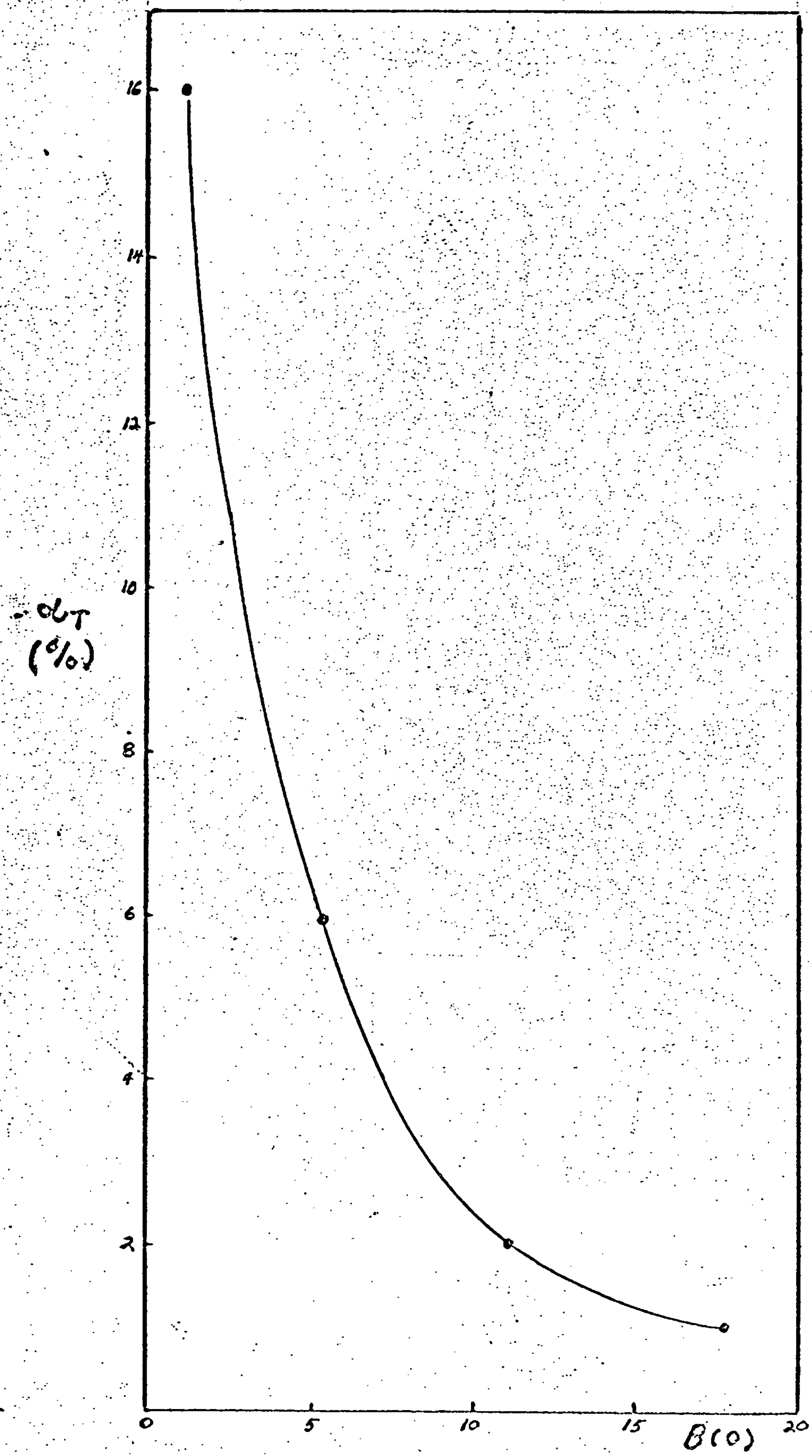

Figure 5. Trapped light ratio α_T versus axial gain B(0) for 4 screens of the AM series.

TABLE I

Series AM and AL Sample Screen Parameters and Measured Characteristics

$V \leq 8\%$

Sample	Glass Volume / Binder Volume	Wet Thickness (Mil)	Substrate Transmittance %	Axial Gain B(0)	T_{90} %	T_{45} %	V_{45} %	T_{30} %	V_{30} %	α_T %
AM-1	1.00	2	97	1.07	42	22.6	9	12	9	
AM(2)-1	0.57	2	97	33.1	86	82.1	97	72	92	
AM(3)-1	0.80	2	97	7.19	61	41.7	78	29	71	
AM(4)-1	0.67	2	97	14.2	67	50.9	89	38.6	84	
AM(4)-2	0.67	3	97	18.4	92	81.4	92	66.6	82	
AM(5)-1	0.90	2	97	10.39	78	65.6	86	51.1	71	
AM(5)-2	0.90	3	97	8.63	79	62.8	81.7	46.4	64	
AM-2	1.00	2	97	1.11	42	23	11	11.8	10	16
AM(5)-3	0.89	2	97	5.30	61	44.3	70	30.1	57	5.9
AM(5)-4	0.89	2	47	4.80	47	36.7	76	26.1	62	
AM(3)-2	0.80	2	97	10.95	73	63.4	88	50	73	2.0
AM(4)-3	0.67	2	97	17.68	81	73.5	94	61.5	84	1.05
AM(6)-1	0.89	3	97	8.31	66	54.5	85	41.7	68	
AM(6)-2	0.89	3	47	3.51	30	24.4	84	18.6	67	
AM(7)-1	0.96	3	97	1.88	46	28.4	36	16.5		
AM(7)-2	0.96	3	97	4.23	57	41	67	28	54	

TABLE I - Continued

Sample	Glass Volume / Binder Volume	Wet Thickness (Mil)	Substrate Transmittance %	Axial Gain B(0)	T_{90} %	T_{45} %	V_{45} %	T_{30} %	V_{30} %	α_T %
AM(7)-3	0.96	3	97		49					
AM(7)-4	0.96	3	47		21					
AL-4	1.0	3	97	5.30	56	38.6	72	26.3	62	
AL-5	1.0	3	47	2.52	26	18.6	72	12.6	62	
AL-2	1.0	3	97	2.87	53	23.6	49	20.9	43	